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ABSTRACT

The paper presents the thesis that experienced physicians, while diagnosing routine cases, are operating upon knowledge structures that are distinctively different from those of novice physicians and students. In the course of their medical training, students develop rich, elaborated causal networks, explaining the causes and consequences of disease in terms of general underlying pathophysiological processes. Through extensive and repeated application of knowledge and exposure to patient problems, the network type of knowledge organization is replaced by list-like structures called "illness scripts." As these scripts are verified through experience they become "instance scripts." Finally, the various knowledge structures develop through a sedimentation process into multiple layers which are accessed when ontologically more recently acquired structures fail to adequately represent a clinical problem. Research evidence for each of these stages and types of knowledge structure is summarized. Contains 20 references. (DB)

Transitory Stages in the Development of Expertise in Medicine: Review of the Evidence

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In this paper, a new theory on the development of expertise in medicine will be sketched and evidence supporting this theory will be presented. Our central thesis is that experienced physicians, while diagnosing routine cases, are operating upon knowledge structures that are distinctively different from those of novice physicians and students. These knowledge structures which we describe as "illness scripts," emerge from continuing exposure to patients and are, therefore, largely the result of extended practice. These illness scripts contain relatively little knowledge about pathophysiological causes of symptoms and complaints but a wealth of clinically relevant information about disease, its consequences and the context under which the illness develops. Illness scripts seem to exist at various levels of generality, ranging from representations of categories of diseases to representations of individual patients seen before. Indeed, one outstanding feature of our theory is the assumption that physicians actually use the memories of previous patients while diagnosing a new case (Allen, Norman, & Brooks, 1988).

Our position can be summarized as follows: In the course of their medical training, students rapidly develop rich, elaborated *causal networks* explaining the causes and consequences of disease in terms of general underlying pathophysiological processes. However, through extensive and repeated application of knowledge acquired and particularly, through exposure to patient problems, these declarative networks become compiled into diagnostic labels or high level, simplified causal models explaining signs and symptoms. At the same time, a transition takes place from a network-type of knowledge organization to list-like structures called *illness scripts* . While solving a problem, a physician searches for an appropriate script and when he has selected one, he will tend to match its elements to the information provided by the patient. In the course of this script verification process the script becomes *instantiated.* Instantiated scripts in turn, do not become decontextualized after use but remain available in memory as episodic traces of previously analyzed patients and will be used in the diagnosis of future similar problems. And finally, the knowledge structures acquired during the different stages of development: Pathophysiological networks, compiled networks, illness scripts and instance scripts, do not decay, become inert or inaccessible. They *sedimentate* into multiple layers which are accessed when ontologically more recently acquired structures fail in producing an adequate representation of a clinical problem.

The evidence supporting the idea of transitory stages in the development of expertise is largely based on studies of the way subjects of different levels of medical expertise represent clinical cases describing the complaints, signs and symptoms of a particular patient. Typically, subjects study half a page of text for a few minutes and after the text has been removed, they are requested 1. to state a most likely diagnosis for the case, 2. to recall whatever they may remember from the text and 3. to explain the signs, symptoms and complaints in terms of underlying causal, pathophysiological processes, principles or mechanisms. It is assumed that the recall of the case depicts the subject's problem representation or "problem model" (Kintsch & Greeno, 1985), since the nature and the amount of the recall is dependent on the knowledge structures activated to comprehend the text. In addition, it is assumed that the pathophysiology protocol reflects the knowledge structures themselves (Patel & Groen, 1986). Usually, both recall and pathophysiology protocols are segmented into sets of propositions, using one of the available approaches (e.g. Frederiksen, 1975). The number of propositions recalled or produced is recorded, and their interrelationships are graphically represented as a semantic network.

Evidence for the acquisition of elaborate causal networks and their subsequent compilation. Recall performance in the processing of clinical cases by subjects in the early years of medical education invariably shows a steep increase in the number of propositions recalled (Claessen & Boshuizen, 1985; Hassebrock, Bullemer & Johnson, 1988; Muzzin, Norman, Feightner & Tugwell, 1983; Patel & Medley-Mark, 1986). These results suggest that the knowledge structures mobilized in the processing of clinical cases become more elaborate, richer and better organized. However, the same studies generally show that recall performance of subjects involved in patient care actually *decreases* with increasing expertise. Expert-physicians typically recall less propositions than first-year medical students. This phenomenon has become known as the "intermediate effect" in clinical case representation studies, because recall seems to be inversely U-shaped related to expertise. In an attempt to find the source of the intermediate effect, Schmidt, Boshuizen and Hobus (1988) asked subjects of five different levels of expertise, ranging from lay persons to internists to study a case of acute bacterial endocarditis. The number of propositions recalled displayed a clear-cut intermediate effect: Second- and fourth-year medical students had the highest recall. In addition, a strong intermediate effect was demonstrated in the number of propositions produced in the pathophysiology protocols. Recall and pathophysiology output were correlated .51. Analysis of the pathophysiology networks, derived from the subjects' protocols, showed that extensive knowledge compilation takes place as soon as subjects become exposed to actual patients, compilation being strongest among the internists. In addition, Schmidt et al. (1988) manipulated the amount of time available for processing the clinical case. They were able to show that if processing time is restricted, the intermediate effect in both recall and pathophysiology disappears. From these data, they conclude that students and experienced physicians represent clinical cases in different ways, because in the process of understanding the text, both groups use functionally different knowledge. Provided they have sufficient time, medical students consciously process causal pathophysiological knowledge activated by cues embedded in the text. Physicians however, only pick up information that is directly relevant to the solution of the problem, because their knowledge of disease, its enabling conditions, causes and consequences, has been etched by continuous exposure to hundreds of patients. The resultant structures are highly compiled in order to meet the demands of their profession.

Evidence for the existence of illness scripts as cognitive entities in experts

Feltovich and Barrows (1984) define an illness script as a list containing information about patients relevant to a specific disease. Table 1 shows their generic model of an illness script.

Table 1. Generic illness script (Feltovich & Barrows, 1984)

Illness scriptfi enabling conditions, fault, consequences

  Enabling conditions fi predisposing factors, boundary conditions, hereditary factors, etc.

    Predisposing factor sfi compromised host factors, travel, drugs, etc.

    Boundary condition sfi age, sex, etc.

  Faultfi invasion of tissue by pathogenic organism, inadequate nutrient supply, inability of tissue to survive, etc.

  Consequencesfi complaints, signs, symptoms

    Complaintsfi etc.

An illness script consists of a series of rewrite rules that enables one to describe patients and their diseases at any required level of specificity. It is important to note that this kind of cognitive structure is essentially a list (although of course, there is a pathophysiological layer underneath it holding the elements together). An implication of list structures is that they tend to be recalled in a fixed order, and this is precisely what has been demonstrated in various studies. Claessen and Boshuizen (1985) for instance, found that, with increasing expertise, subjects increasingly tended to group elements together in a way compatible with the illness script format. Their study was flawed however, in the sense that the stimulus material already had a script structure. Coughlin (1986) however, presented novices and experts with either a script- or a scrambled version of a clinical case. Whereas the recall of the novices was greatly affected by the experimental manipulation, the recall of the experts displayed the typical script-like structure, irrespective of the structure of the text presented. These data indicate that, while processing a case, experts store patient information in pre-existing linear structures that have a fixed order.

In a study of the role played by enabling conditions in the activation of an appropriate script, Hobus, Hofstra, Boshuizen and Schmidt (1988) presented experienced and inexperienced family physicians with 18 clinical cases, each consisting of a patient chart, a picture of the patient and his main complaint. The patient chart and the picture were carrying enabling conditions information like age, sex, previous diseases, occupation, drug use, etc. The experimental manipulation consisted of presenting the complaint either with or without the patient chart and the picture. The task of the subjects was to formulate a diagnostic hypothesis based on the available information. When presented with all the information, the experienced physicians produced twice as many accurate diagnoses as compared with the inexperienced physicians. However, the number of accurate diagnoses produced by the experienced physicians decreased with almost 100% when no enabling conditions information was provided, whereas the inexperienced physicians were only marginally affected. These results demonstrate the overriding importance of knowledge about conditions enabling disease in the activation of relevant illness scripts. In addition, they demonstrate that this knowledge is only acquired through extensive exposure to practice and illustrates that practice not only results in knowledge compilation as some authors seem to suggest (Anderson, 1983) but provides opportunities for acquiring new --contextual-- information essential to the development of expertise.

Evidence for the use of instances in the diagnosis of new cases.

According to Brooks (1987), human ability to categorize objects is as much determined by an earlier experience with an object that looked much like the present one, as it is determined by abstract, decontextualized rules linking sets of features to category names. His work prompted Norman and his associates (Allen, Brooks, & Norman, 1989; Norman, Brooks, Allen, & Rosenthal. in preparation) to test the hypothesis that diagnostic performance of physicians and medical students is influenced by exposure to previous patients who looked like the present patient. In one experiment (Allen, Norman & Brooks, 1988), first-year medical students were required to study a set of rules to diagnose dermatological diseases. Next, they were presented with 24 slides displaying six different diseases to practice the rules. The slides were shown several times and feedback was provided after each attempt in order to ensure the learning of the rules. The experimental manipulation involved the choice of the slides used in the practice set. Two different sets were used, with the intention of biasing the diagnosis of slides in the test series. For example, if one of the ambiguous test slides was a case of lichen planus on the wrist which might be confused with contact dermatitis, then one practice set would contain a similar lichen planus on the wrist, and the other would contain a similar appearing contact dermatitis on the wrist. All subjects received the same test slides. If subjects' diagnostic behavior was based on the application of the rules, no incorrect diagnoses were to be expected, since the location of the skin disease or other contextual aspects were not in any way part of the rules (in fact, they were irrelevant to the diagnosis of the particular disease), and subjects had the rules in front of them. If however, there behavior was influenced by seeing similar exemplars from another disease,

incorrect diagnoses were to be expected. When shown an appropriate analogy , subjects correctly diagnosed the test slide 94% of the time. Conversely, when shown a look-alike but wrong analogy, only 38% of subjects selected the correct diagnosis. The influence of prior examples was apparent even after a week and exposure to further examples. These data suggest that diagnostic performance is at least to the same extent determined by previous experience with similar exemplars as it is by the application of diagnostic rules. Studies undertaken with experts show similar results .
In conclusion, the available evidence seems to suggest that physicians store experiences with concrete patients in memory and use these episodic traces in the diagnosing of similar new patients.

Evidence for the availability of multiple-layered knowledge structures in experts
In a series of studies, Patel and her colleagues (e.g. Patel, Evans, & Chawla, 1986) have demonstrated that the amount of pathophysiological reasoning in protocols of subjects decreases with an increase of level of expertise. Thus, the more expert one is, the less one seems to rely on causal explanation to arrive at a diagnosis. These findings are in accordance with the studies cited above; they imply that the nature of the cognitive structures upon which subjects operate changes with level of expertise. In addition however, Patel was able to show the same phenomenon to occur among physicians of the same level of expertise. In a study by Patel, Arocha and Groen (1986), experts from two distinct medical specialities were compared on tasks both within and across their domains of expertise. They demonstrated that physicians solving a problem outside their domain of expertise, produced more pathophysiological explanations then within their domain of expertise. In addition, within the same domain, experts who more involved in clinical research and hence, saw less patients also tended to rely more on pathophysiological explanation than their colleagues who saw patients on a daily basis. Finally, Boshuizen (1988) demonstrated that experts dependent on the specific task one requires from them are able to retrieve pathophysiological knowledge, suggesting that this kind of knowledge does not decay or become inaccessible. It is just not used while being confronted with routine cases, but is available when a difficult case is presented and available illness script knowledge does not apply or is not available. These studies seem to support the notion that experts have knowledge available in different layers. Illness script knowledge represents the preferred level for experts but when a case is presented for which no knowledge of that kind exists they will "regress" to sub-expert or advanced-student levels of reasoning, involving the application of causal, pathophysio-logical, reasoning.

Conclusion

The theory of expertise development in medicine presented in this paper deviates from other proposals (e.g. Lesgold, 1984) in several ways. The first is that it assumes that the development of expertise can described as the progression through a series of transitory stages, each of which is characterized by functionally different knowledge structures underlying performance Second, knowledge acquired at different points in time has a distinctly different organization; earlier forms tending to be organized in causal networks, more recent forms being structured as frames or scripts. Third, it is assumed that knowledge acquired in different stages form layers in memory through a sedimentation process. Fourth, these knowledge sediments, although usually not applied anymore in subsequent stages in the development of expertise, remain available for use when ontologically more recently acquired structures fail in producing an adequate representation of a clinical problem. And fifth, episodic traces of clinical problems previously analyzed seem to be extensively used in the representation and solution of new cases.

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